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Recoil-ion momentum spectroscopy for $\text{He}^{2+} + \text{He}$ electron capture reactions

M Alessi¹, P Focke² and S Otranto³

¹INVAP SE, Av. L. Piedrabuena 4950, 8403CPV, S. C. de Bariloche, Argentina.

²Centro Atómico Bariloche, Av. Bustillo 9500, 8400 S. C. de Bariloche, Argentina.

³IFISUR and Departamento de Física, Universidad Nacional del Sur, 8000 Bahía Blanca, Argentina.

²focke@cab.cnea.gov.ar

Abstract. Electron capture reactions for $^3\text{He}^{2+}$ collisions on He at impact energies in the range 40 keV-300 keV have been studied using the Cold Target Recoil-Ion Momentum Spectroscopy setup which has recently become operational at the Centro Atómico Bariloche. State-selective charge exchange cross sections were obtained and in this work we present recoil-ion transverse momentum distributions. For targets with residual thermal motion, we show that the implementation of a back-projection algorithm based on the transverse momentum distribution component along a direction perpendicular to the jet direction provides results in agreement with those obtained by using previously cooled targets. Present results nicely fit the gaps in the datasets already published by other laboratories and are found to be in good agreement with classical trajectory Monte Carlo simulations.

1. Introduction

During the past 20 years the cold-target recoil-ion momentum spectroscopy (COLTRIMS) method has been implemented in several laboratories worldwide and has led to an important advance in our current understanding of several atomic and molecular collision processes [1-8]. In particular, a COLTRIMS setup has been recently turned operational at the Centro Atómico Bariloche [9-11] and has been married to the Kevatron accelerator that spans a high voltage range from 20 kV up to 300 kV. Initial studies performed with this device were focused on the determination of state-selective cross sections [10]. In contrast to ionization processes, charge exchange reactions lead to discrete values for the longitudinal momentum acquired by the recoil-ion after the collision (p_l). The state-selective charge exchange cross sections, in this sense, can then be obtained from the p_l recorded distribution. Projectile angular scattering, on the other hand, can be inspected via the transverse momentum acquired by the recoil-ion (p_t). Initial studies with a target solely cooled by the adiabatic expansion in the nozzle-skimmer clearly showed a non-isotropic distribution along the plane determined by the p_{t-y} and p_{t-z} components. The coordinate system used is as described in ref. [9, 10]. This non-symmetric distribution reflected the residual thermal motion in the target atom which elongated the width of the distribution in the p_{t-y} direction (in the gas jet direction). Later on, a liquid N_2 cooling stage was implemented nicely leading to p_t distributions which were completely symmetrical in terms of its components p_{t-y} and p_{t-z} .

In this work, we show that charge exchange p_t distributions obtained for setups with and without pre-cooling stages for the target, provide similar results if a back-projection algorithm for the p_t



component, that is not thermally affected, is considered. In particular, we consider electron capture reactions for ${}^3\text{He}^{2+}$ collisions on He at impact energies in the range 40 – 300 keV proper of our Kevatron accelerator. The present state-selective charge exchange cross sections and p_t distributions are also contrasted to classical trajectory Monte Carlo simulations which incorporate dynamical screening (dCTMC) [12].

2. The back-projection algorithm

In figure 1 we show the transverse momentum distribution at impact energy of 60 keV. The p_y and p_z distributions are shown. p in the abscissa is used for p_y or p_z . All distributions are normalized at the peak value.

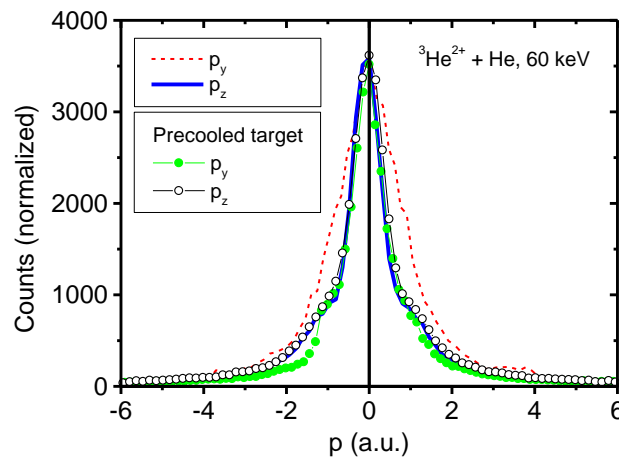


Figure1. Transverse momentum distributions for 60 keV ${}^3\text{He}^{2+}$ collisions on He.

From the cylindrical rotation symmetry of the present collision system it is expected that both distribution should have the same shape. For a He gas jet obtained from gas in the reservoir at room temperature the distributions are different. The p_y momentum distribution is broader than the p_z distribution. This shows that the cooling from adiabatic expansion in the nozzle is not enough to reduce the thermal initial momentum of the target along the jet direction. On the contrary, along the z direction, due to geometrical cooling by the skimmer collimation of the gas jet, the residual momentum can be considered irrelevant. When the gas jet originates from a precooled gas both distribution show the same shape, as expected and are also nearly equal as the p_z distribution that results from a non-precooled target.

The transverse momentum p_t for the recoil ion is given by:

$$p_t = \sqrt{p_y^2 + p_z^2} . \quad (1)$$

In the case of measurements obtained with a non-precooled target, the p_y distribution is affected by residual thermal broadening, and equation (1) is not applicable. However, a projection of the transverse momentum along the z -axis is not affected by the thermal motion of the target. For the latter the projection $P(p_z)$ is (here $p = p_t$):

$$P(p_z) = 2 \int_{p_z}^{\infty} \frac{f_c(p)p}{\sqrt{p^2 - p_z^2}} dp, \quad (2)$$

here $f_c(p)$ is the transverse momentum distribution resulting from the collision. Equation (2) for the p_z -projection is known as the Abel transform and its inverse reads:

$$f_c(p) = -\frac{1}{\pi} \int_p^\infty \frac{d}{dp_z} [P(p_z)] \frac{1}{\sqrt{p_z^2 - p^2}} dp_z. \quad (3)$$

Equation (3) then provides a way to obtain transverse momentum distributions even when a thermally affected target is being used.

In figure 2 we show the transverse momentum distributions for single capture to the ground and excited states for a precooled target, using equation (1), and a non-precooled target using the back-projection procedure of equation (3).

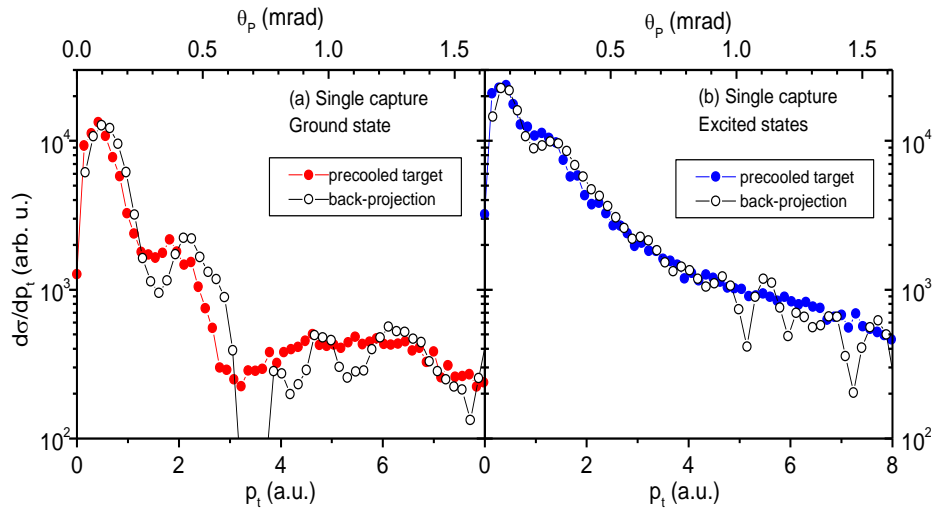


Figure 2. Transverse momentum distributions for 60 keV³He²⁺ collisions on He. Back-projected results and pre-cooled data are explicitly shown. θ_p is the projectile scattering angle.

The result is satisfactory showing that a back-projection procedure may be applied in the cases in which the target is not cool enough or when the target gas that cannot be precooled, such as Ar or Ne, is used. The procedure has also been checked more extensively with single capture reactions on the H⁺ + He system in the range from 25 to 200 keV.

Applying equation (3) to our measurements we obtained the transverse momentum distributions and compared them with results from other laboratories where a precooling stage has been used. In figure 3 we show some of these results. Present experimental data for the transverse momentum distributions are compared to those obtained by Mergel *et al.*[13] at 62.5 keV/amu with a 14 K external cooling system that provides an inner target temperature of 0.1 K. dCTMC results are also shown and found to be in good agreement with the data, with the exception of the deep structure at 1.5 a.u. that cannot be reproduced by the simulation. In figure 4, present experimental charge exchange distributions at 67 keV/amu in terms of the projectile scattering angle θ_p are shown, and compared to those obtained by Schöffler *et al.*[14] at 60 keV/amu. Good agreement is found among both sets of data except for scattering angles larger than 0.4 mrad.

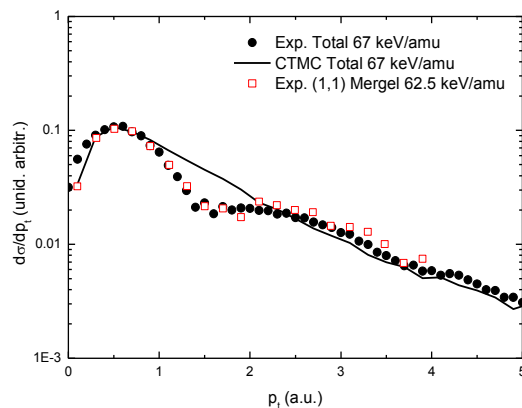


Figure 3. ${}^3\text{He}^{2+}$ collisions on He. Total transverse momentum distributions (experimental and CTMC). Solid circles, present data; data of Mergel *et al* [13].

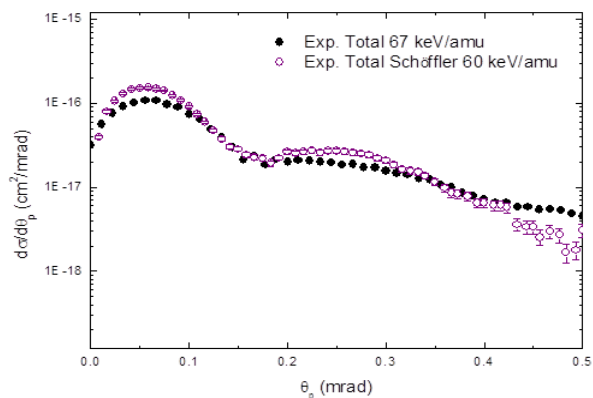


Figure 4. ${}^3\text{He}^{2+}$ collisions on He. Experimental scattering angle distributions. Solid circles, present data; data of Schöffler [14].

3. Conclusions

Electron capture reactions for ${}^3\text{He}^{2+}$ collisions on He have been studied at impact energies in the range 40 - 300 keV using the COLTRIMS technique. Recoil-ion transverse momentum distributions were presented for state-selective charge exchange collisions. A back-projection algorithm based on the transverse momentum distribution component along a direction perpendicular to the jet direction provides results in agreement with those obtained by using previously cooled targets. Present results nicely fit the gaps in the datasets already published by other groups.

Acknowledgments

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